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RESEARCH DEPARTMENT **REPORT**

LF AND MF SKY-WAVE PROPAGATION:

a comparison of measurements made at sunset and sunrise

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Summary

The strength of LF and MF sky-wave signals is greatest at night and weakest during the day. The increase in field strength which occurs at sunset has been extensively studied but less is known about the decrease which occurs at sunrise. This Report describes a series of measurements made by members of the European Broadcasting Union (EBU) which covers both the sunrise and sunset periods. The results show that during the sunset period the new measurements agree closely with the existing CCIR curve but that the sunrise measurements indicate that the existing CCIR curve is inaccurate, and a modified curve for MF use is proposed. The LF measurements show significant seasonal variations and it is suggested that a set of seasonal curves for LF, for use in temperate regions, should be considered in the future.

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1. INTRODUCTION

LF and MF sky-wave field strengths are greatest at night and weakest during the day. The increase in field strength which occurs at sunset has been extensively studied in the past but less is known about the decrease which occurs at sunrise. As the early morning is an important period for sound broadcasting, members of the EBU referred to in Section 6 have carried out a series of measurements which cover the sunrise period as well as the sunset period. The transmitter details, propagation paths and organisations responsible for the measurements are given in Tables 1 and 2. The measurements are compared in this Report, both with each other and with a CCIR curve which is derived from earlier measurements.

2. METHOD OF ANALYSIS

All the measurements were plotted on a common scale for comparison. Following the method of presentation adopted by RAI, they were referred in time to the hours of sunrise and sunset at the path mid-point and the months arranged in seasonal groups as follows:

WINTER	November, December, January, February
SPRING and AUTUMN ...	March, April, September, October
SUMMER	May, June, July, August

Plots for individual months within these groups were superimposed with their sunset or sunrise time aligned, to enable average seasonal curves to be drawn.

On some paths, the field strengths measured after sunrise and before sunset were influenced by the presence of the ground wave. If the strength of the ground wave is known, for example from measurements made at mid-day during the summer, then it is possible to extend the sky-wave curves into the daytime period using the following method. Fig. 1 is a vector diagram which represents a steady ground wave E_g and a randomly-phased sky-wave E_s. It is apparent that for a fixed amplitude of E_s the resultant field strength E which is exceeded for 50% of the time is given by:

$$E = (E_g^2 + E_s^2)^{1/2} \quad \text{........................} \quad (1)$$

This is a reasonable approximation if E_s is taken as the short-period median value of a variable-amplitude sky-wave. Thus E_s can be calculated with reasonable accuracy from the measured median field strength E if E_g is known, provided E_g is not dominant. Equation (1) was used to extend the sky-wave field strength curves into the daytime period wherever possible.

To enable sunset and sunrise measurements made on different paths to be compared, the curves for individual paths were aligned vertically so that the sky-wave field strengths measured 6 hours after sunset (the CCIR reference time) coincided. At MF, care had to be taken to distinguish between E and F layer reflections; this is discussed in the next section.

3. MF MEASUREMENTS

Measurements were made by RAI on five paths and by TDF on one path during the sunset and sunrise periods, and by ARD/ZDF[1,2] throughout the 24 hour period. Table 1 gives details of these measurements.

The effective monopole radiated powers (e.m.r.p.s) quoted in Table 1 were derived from the published transmitter powers by adding 2.3 dB to take account of the gains of the transmitting aerials.

Although this Report is concerned with diurnal field strength variations, it is of value to use the data given in Table 1 to estimate both the ground-wave field strength and the sky-wave field strength late at night. This assists in the identification of the ground-wave when the latter predominates, and in the identification of E-layer reflection when F-layer reflections are also possible.

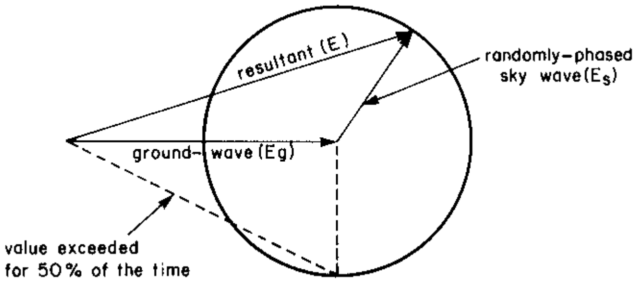
resultant (E)
randomly-phased sky wave(E_s)
ground-wave (Eg)
value exceeded for 50% of the time

Fig. 1 - Combined ground-wave and sky-wave.

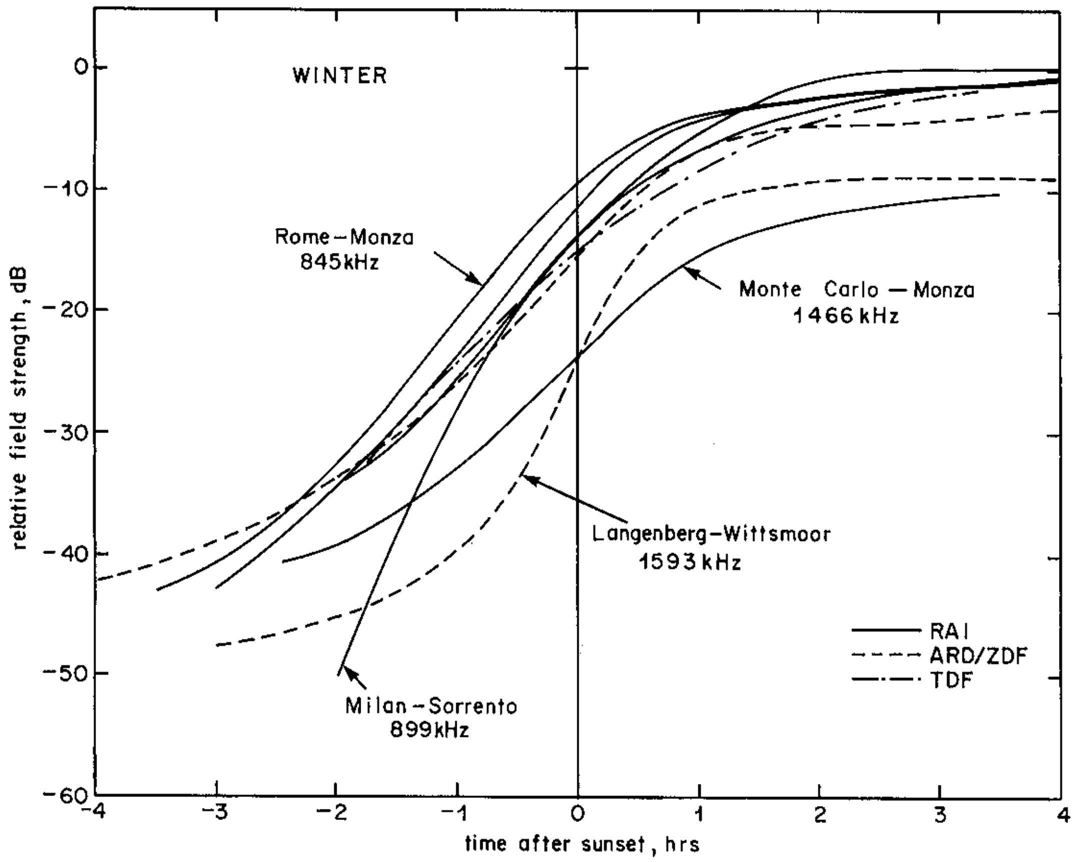

Fig.2(a) - MF sky-wave field strength in winter.

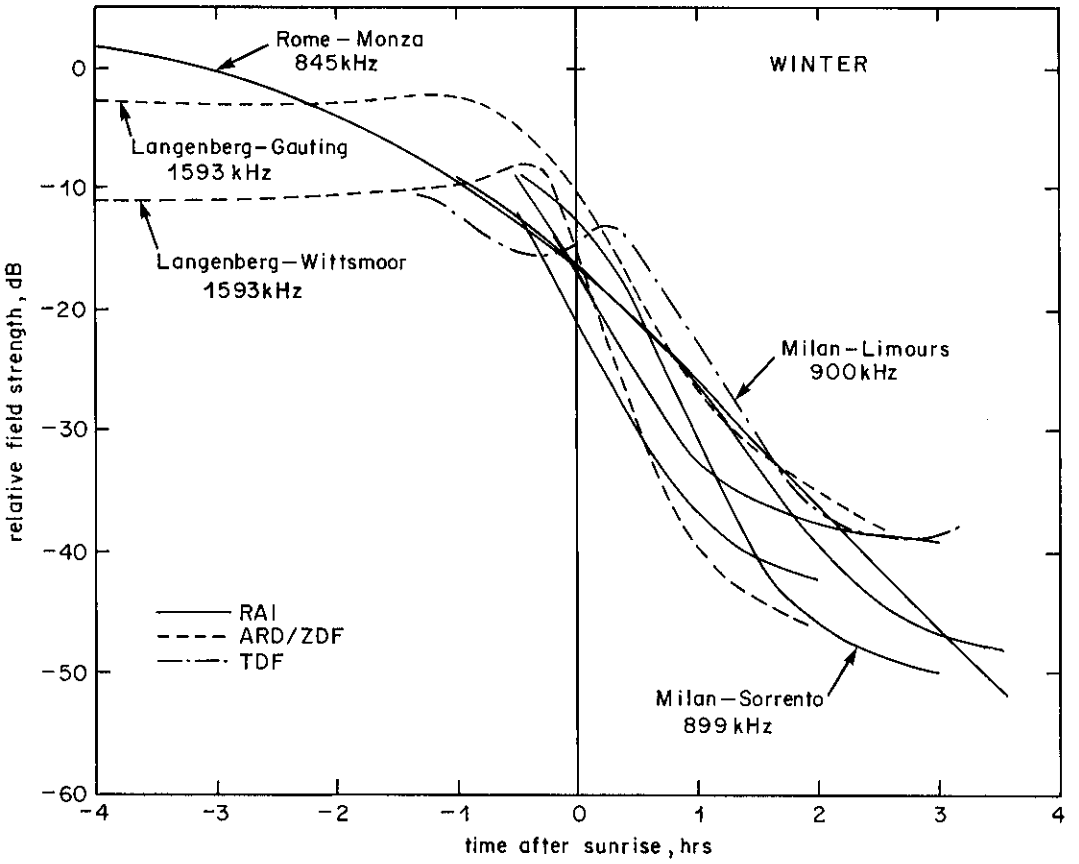

Fig.2(b) - MF sky-wave field strength in winter.

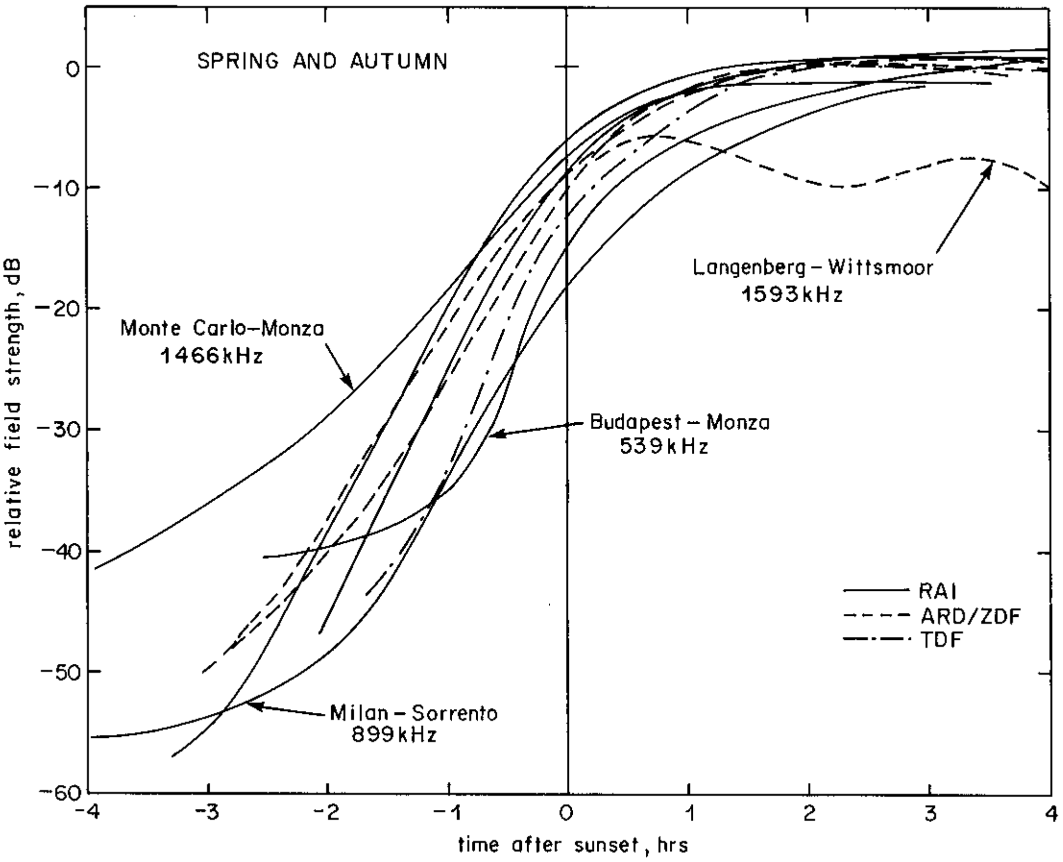

Fig.3(a) - MF sky-wave field strength in spring and autumn.

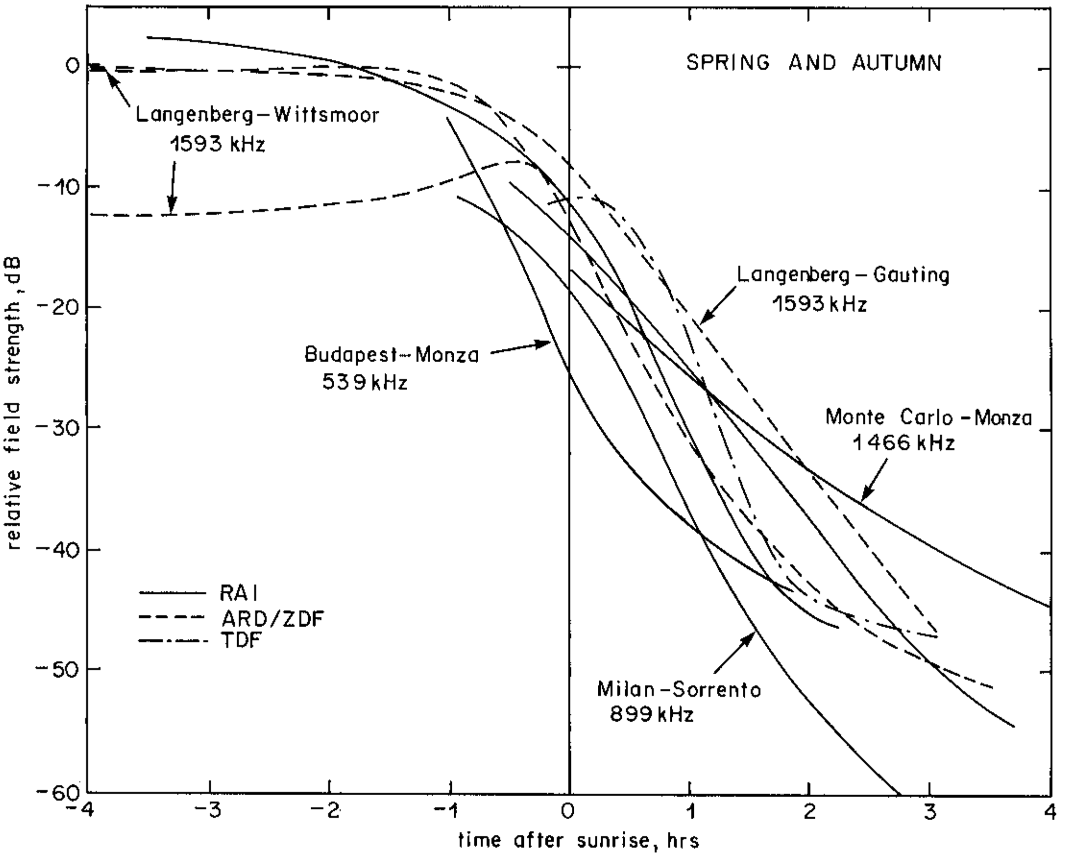

Fig.3(b) - MF sky-wave field strength in spring and autumn.

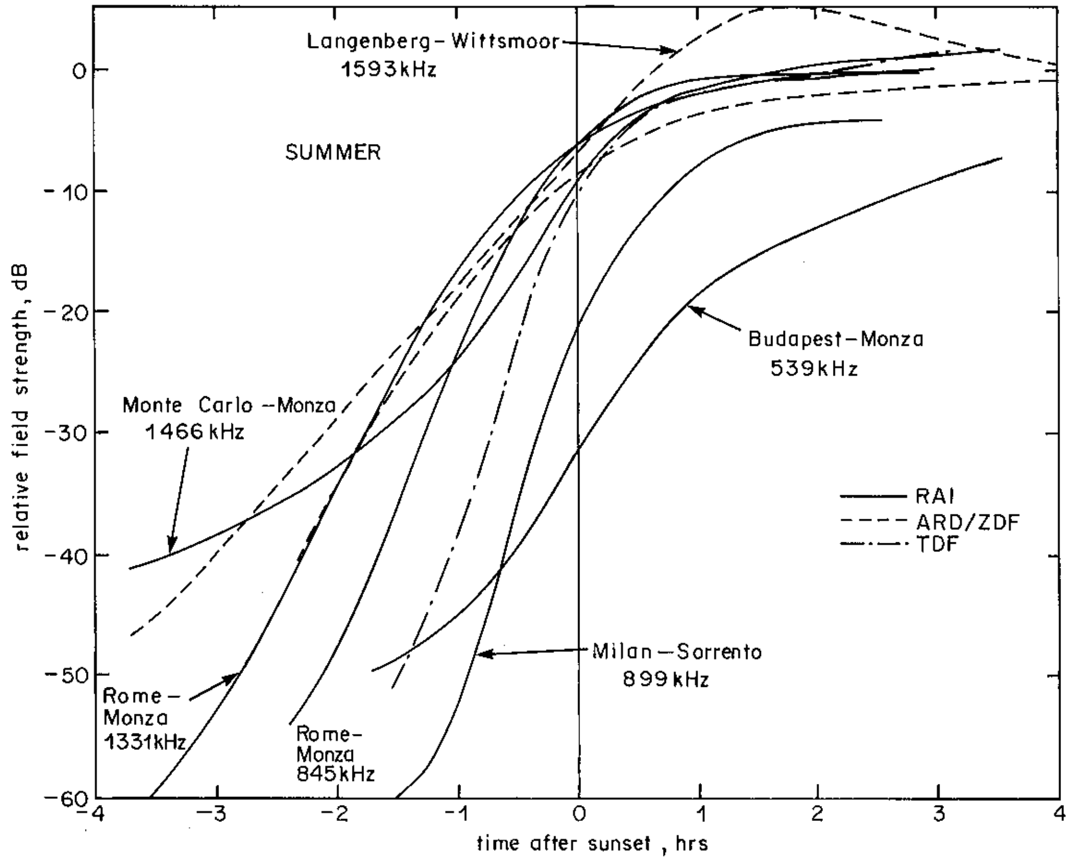

Fig.4(a) - MF sky-wave field strength in summer.

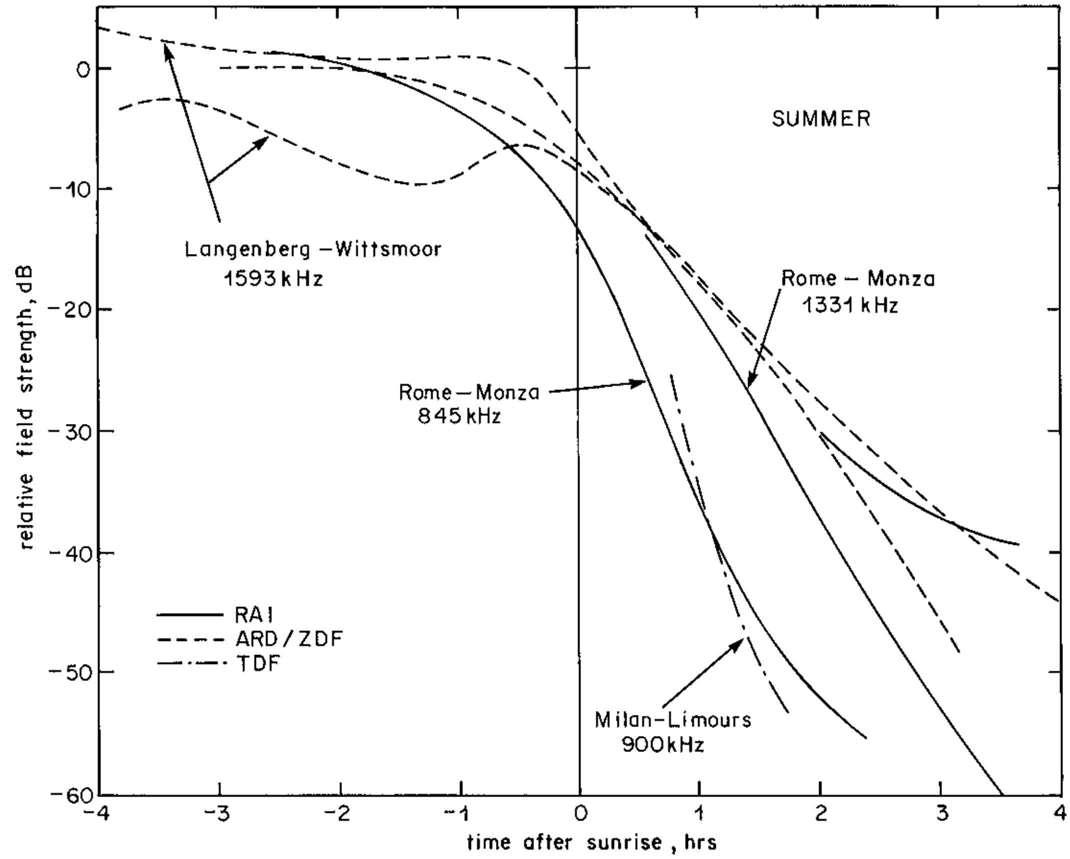

Fig.4(b) - MF sky-wave field strength in summer.

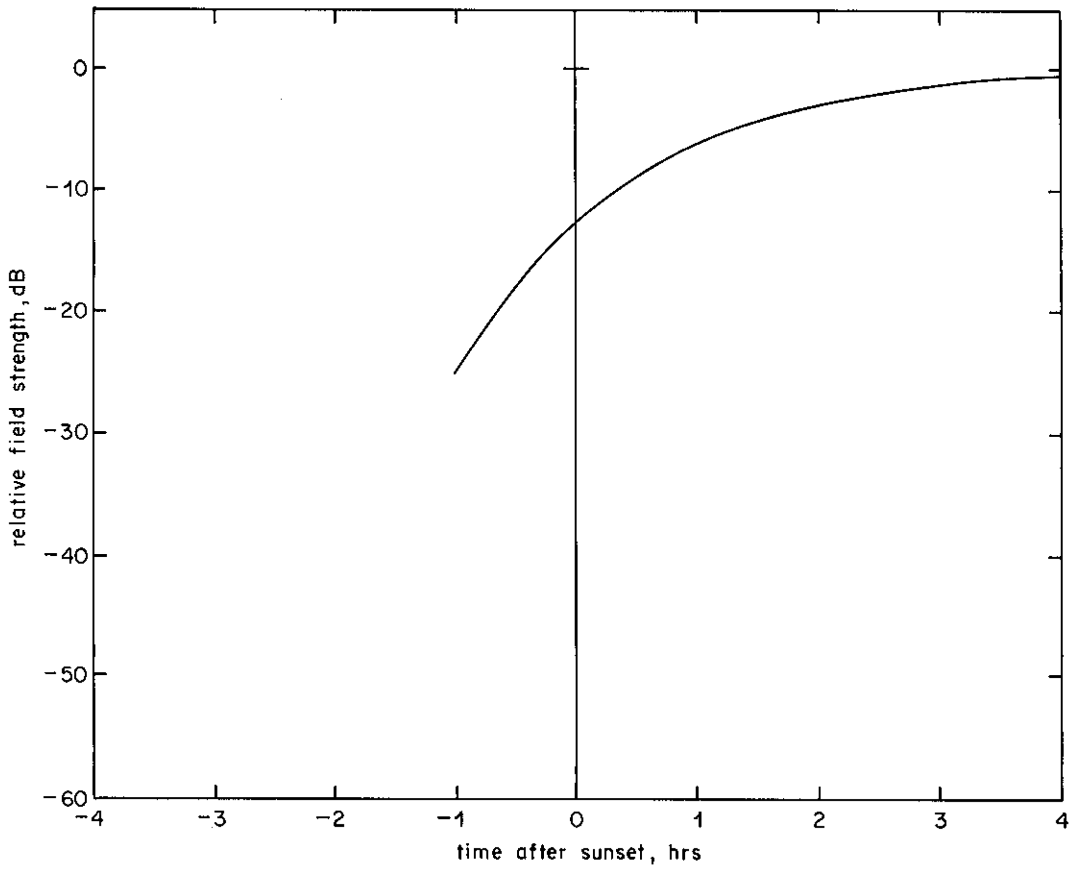

Fig.5(a) - CCIR diurnal variation curve.

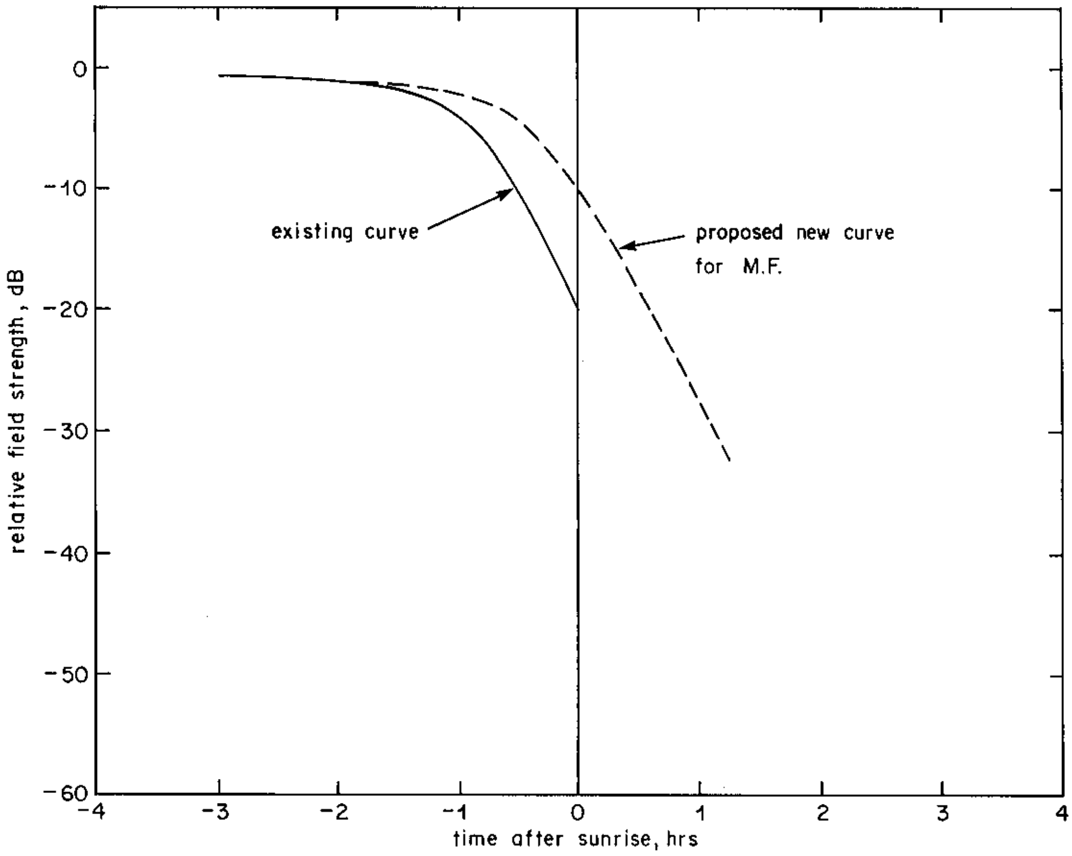

Fig.5(b) - CCIR diurnal variation curve.

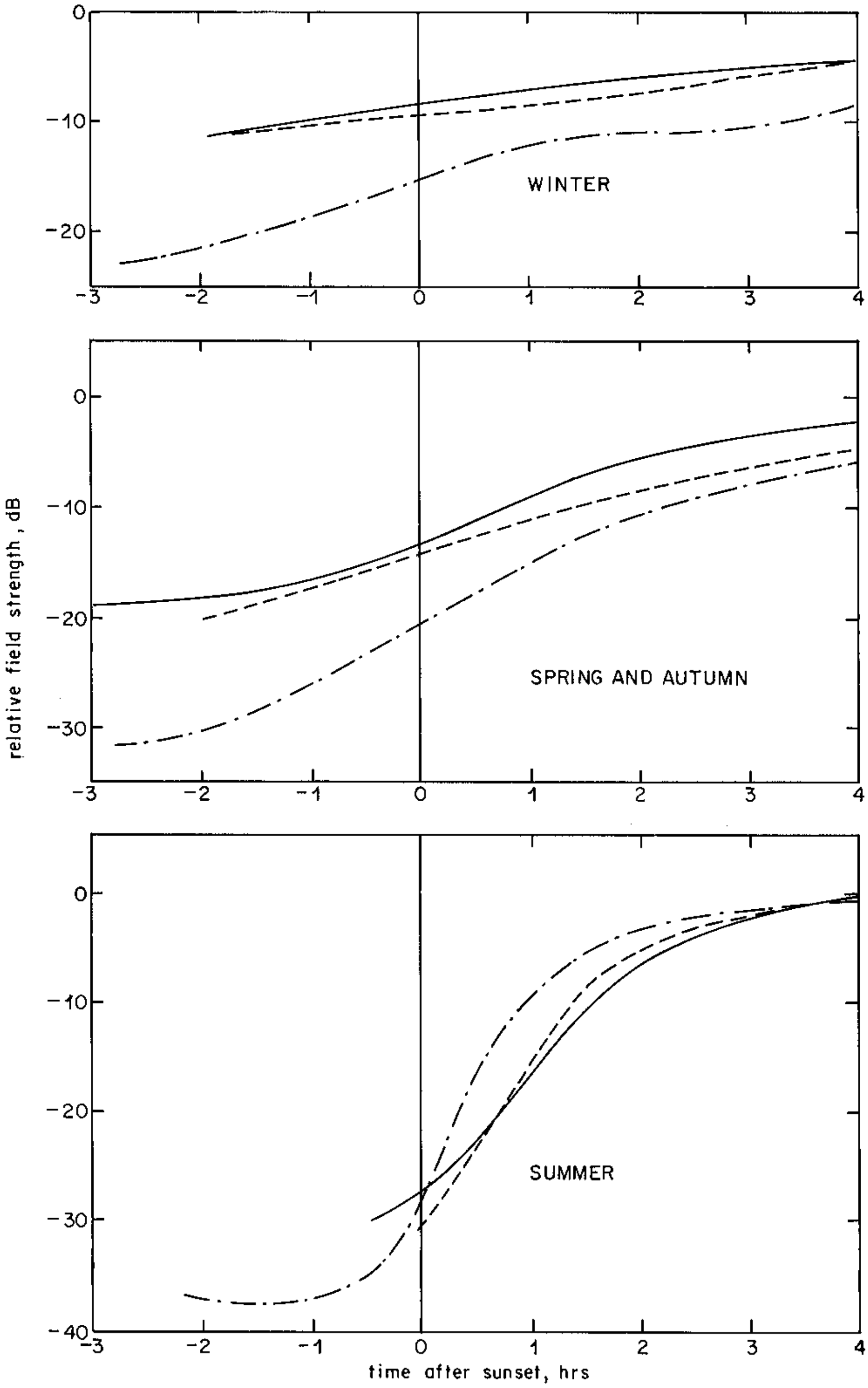

Fig.6 - LF sky-wave field strength at sunset.

- - - - - Warsaw - Helsinki 227 kHz

——— Warsaw - Kingswood 227 kHz

—·—· Tipasa - Kingswood 251 kHz

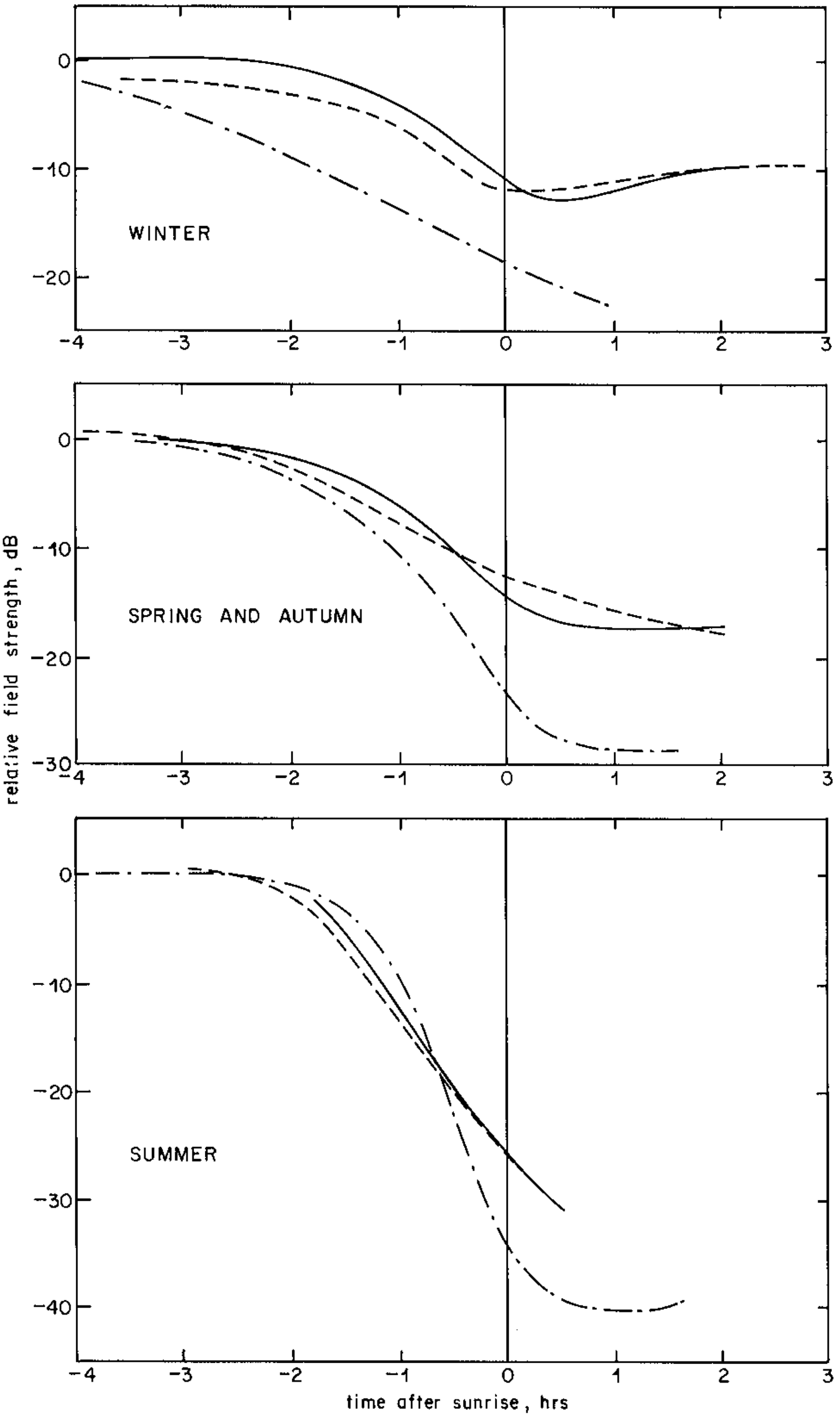

Fig. 7 - LF sky-wave field strength at sunrise.

- - - - - Warsaw - Helsinki 227 kHz
——— Warsaw - Kingswood 227 kHz
—·— Tipasa - Kingswood 251 kHz

TABLE 1.
MF Propagation Paths

PATH	FREQUENCY kHz	GROUND DISTANCE km	E.M.R.P. dB(kW)	GROUND WAVE FIELD STRENGTH dB(μV/m) MEASURED	GROUND WAVE FIELD STRENGTH dB(μV/m) CALCULATED	NIGHT SKY-WAVE FIELD STRENGTH dB(μV/m) MEASURED	NIGHT SKY-WAVE FIELD STRENGTH dB(μV/m) CALCULATED	MEASURED BY
Budapest-Monza	539	771	27.1	19	4-37	66	68	RAI
Rome-Monza	845	508	29.6	29	17-42	75	74	
Milan-Sorrento	899	673	30.1	17	1-26	80	75	
Rome-Monza	1331	508	29.6	19	6-40	76.5	74	
Monte Carlo-Milan	1446	247	28.3	37	31-51	75	74	
Langenberg-Gauting	1593	478	30.1	30	4-23	77	73	ARD/ZDF
Langenberg-Wittsmoor	1593	309	30.1	30	22-41	81	74	
Milan-Limours	900	656	30.1	20	0-26	72	72	TDF

TABLE 2.
LF Propagation Paths

PATH	FREQUENCY kHz	GROUND DISTANCE km	E.M.R.P. dB(kW)	GROUND-WAVE FIELD STRENGTH dB(μV/m) MEASURED	GROUND-WAVE FIELD STRENGTH dB(μV/m) CALCULATED	NIGHT SKY-WAVE FIELD STRENGTH dB(μV/m) MEASURED	NIGHT SKY-WAVE FIELD STRENGTH dB(μV/m) CALCULATED	MEASURED BY
Warsaw-Helsinki	227	925	35	60	66	74	74	YLE
Warsaw-Kingswood	227	1380	35	48	49	70	68	BBC
Tipasa-Kingswood	251	1650	33		32	77	69	BBC

Full details of the BBC measurements are given in Reference 4

3.1 Ground-wave Field Strength

The calculated ground-wave field strengths given in Table 1 were derived from CCIR Recommendation 368-4, assuming mixed land-sea paths where appropriate. The land conductivity was assumed to lie between 1 and 10 mS/m, and the figures given in the table apply to this range of conductivities. They are compared in the table with field strengths measured well after sunrise or well before sunset during the summer. As the field strengths measured at these times were within the range of calculated values, it is reasonable to assume that the observed signals were in fact ground waves.

3.2 Sky-wave Field Strength During the Night

Sky-wave field strengths were calculated by the method described in CCIR Recommendation 435-4, assuming 0.5 λ transmitting aerials, and are therefore the annual median values for 6 hours after sunset. Sea gain was included for the path terminating at Sorrento, where sea water was assumed to extend for 24 km in the direction of the transmitter.

Field strengths measured well after sunset (except on very short paths at frequencies above 1 MHz) give a good indication of the field strength for E-layer propagation at the CCIR reference time of 6 hours after sunset. Average measured values for the whole year are compared in the table with the calculated field strengths. The comparison suggests that the CCIR method tends to underestimate the field strength on some paths.

3.3 Sky-wave Field Strength Variation at Sunset and Sunrise

The RAI measurements were already plotted in seasonal groups as described above. The TDF measurements were grouped in the same way, aligned at sunset and sunrise, and then averaged.

The ARD/ZDF measurements are presented as median field strengths for half-hour periods throughout the day, plotted for individual months. The sunrise and sunset portions of the ARD/ZDF data were re-plotted on the same scale as the RAI and TDF data, the times of sunrise and sunset (calculated as accurately as possible for the path mid-point and for the middle of each month) being indicated on the time axis. Plots for individual months were then superimposed with their sunrise or sunset times aligned, to enable average seasonal curves to be drawn. Direct comparison with RAI and TDF measurements was then possible.

In comparing the three sets of measurements, care had to be taken to distinguish between E-layer reflection late at night, which is taken as the reference condition, and F-layer reflection which occurs on some paths and results in weaker sky-wave signals. F-layer reflection is particularly noticeable on the Langenberg-Wittsmoor path, because the frequency is high and the ground distance is short. The plots in Reference 2 show that the median sky-wave field strength during the short summer nights exceeds 80 dB(μV/m), but in winter it falls to about 70 dB(μV/m) late at night, rising again towards 80 dB(μV/m) just before sunrise. The explanation is believed to be as follows. For the first few hours after sunset reflection takes place from the E-layer. As the ionosphere decays, the wave penetrates the E-layer and is reflected from the F-layer. This condition persists until shortly before sunrise, when the E-layer is rapidly enhanced. Pen recordings made by the BBC on similar paths support this theory; it is found that the rapid fading characteristic of F-layer reflection is followed at sunrise by about half an hour of slow fading which indicates reflection from the E-layer.

The results of the comparisons are shown in Figs. 2, 3 and 4. Each curve corresponds to a particular path and most of the paths are identified. It will be seen that Figs. 4(a) and 4(b) have two distinct curves for the Langenberg-Wittsmoor path. Separate curves had to be drawn because, in some months, E-layer propagation continued until sunrise while in other months propagation late at night was via the F-layer. Both curves are similar after sunrise.

Figs. 5(a) and 5(b) show the sunset and sunrise portions of the CCIR diurnal variation curve (Fig. 3 of Recommendation 435-4) drawn to the same scale as Figs. 2 to 4. Comparison of Fig. 5 with the measurements shows that the latter are consistent with the sunset part of the CCIR curve. Although the measurements show considerable variation from one path to another it should be borne in mind that the CCIR curve for sunset was derived from a much larger number of measurements which showed similar variations between paths[3]. The present measurements therefore provide no grounds for proposing any modification to the sunset portion of the CCIR curve, although it might be argued that the representation of all paths by a single curve is an over-simplification.

Comparison of the measurements with the sunrise portion of the CCIR curve suggests that the latter is inaccurate, as has been suspected for some time. Since hardly any other sunrise data are available it is reasonable to suggest that the measurements described here should be used to correct the CCIR curve for sunrise. A proposal for a modified curve is shown in Fig. 5(b), and a third order polynomial equation equivalent to this curve is given in Appendix 1.

4. LF MEASUREMENTS

Measurements were made by YLE and the BBC[4] on three paths, details of which are given in Table 2.

Both sets of measurements were replotted on the same scales as the MF measurements, and they are compared in Figs. 6 and 7. The measurements on all three paths show similar trends.

It is of interest to compare Figs. 6 and 7 with the CCIR curve reproduced in Fig. 5. The comparison suggests that the CCIR curve does not adequately describe the diurnal variation at LF because the seasonal variations in temperate latitudes are significant.

No account was taken of this seasonal variation when earlier EBU measurements were analysed[5]. Thus the diurnal variation curve which was derived from this earlier analysis is an annual median curve which agrees reasonably well with the CCIR curve.

A possibility which might be considered in the future is the replacement of the CCIR curve by three seasonal curves for use in the LF band. The use of curves based on the measurements described here should, however be restricted to temperate latitudes. Measurements made in India[6] suggest that the seasonal variation is much smaller in tropical latitudes.

5. CONCLUSIONS

At MF the measurements made at sunset are consistent with the CCIR diurnal variation curve and provide no grounds for proposing any modification to the CCIR curve. The measurements made at sunrise, which are more comprehensive than any previous measurements, suggest that the sunrise portion of the curve is inaccurate. A modified curve is proposed (see Fig. 5(b)).

The LF measurements made at sunrise are also more comprehensive than any previous measurements. Analysis of the LF measurements shows that in temperate latitudes, there is a significant seasonal variation, both at sunset and sunrise, which has hitherto been disregarded. Consideration should therefore be given to the construction of seasonal sunset and sunrise curves for use at LF, but further measurements are desirable. However the use of such curves should be restricted to temperate latitudes because seasonal variations in the tropics are believed to be much smaller.

In the absence of such a set of seasonal curves for LF, it is suggested that the new MF sunrise curve also be used at LF, as this is consistent with the 'average' LF diurnal variation, but account should be taken of a the large seasonal variations.

6. ACKNOWLEDGEMENTS

Acknowledgement is made to the Italian (RAI), French(TDF), West German(ARD/ZDF) and Finnish (YLE) broadcasting organisations for measurement data which, in addition to those from the UK (BBC), provided the basis for this Report.

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APPENDIX

Equation Equivalent to Sunrise Curve

A third-order polynomial equation for calculating the hourly loss factor L_t within the limits of time t hours after sunrise ($-3 < t < 1$) can be used instead of the modified sunrise curve shown in Fig. 5(b).

$$L_t\ (\text{Sunrise}) = 9.597 + 12.215t + 5.617t^2 + 0.857t^3$$